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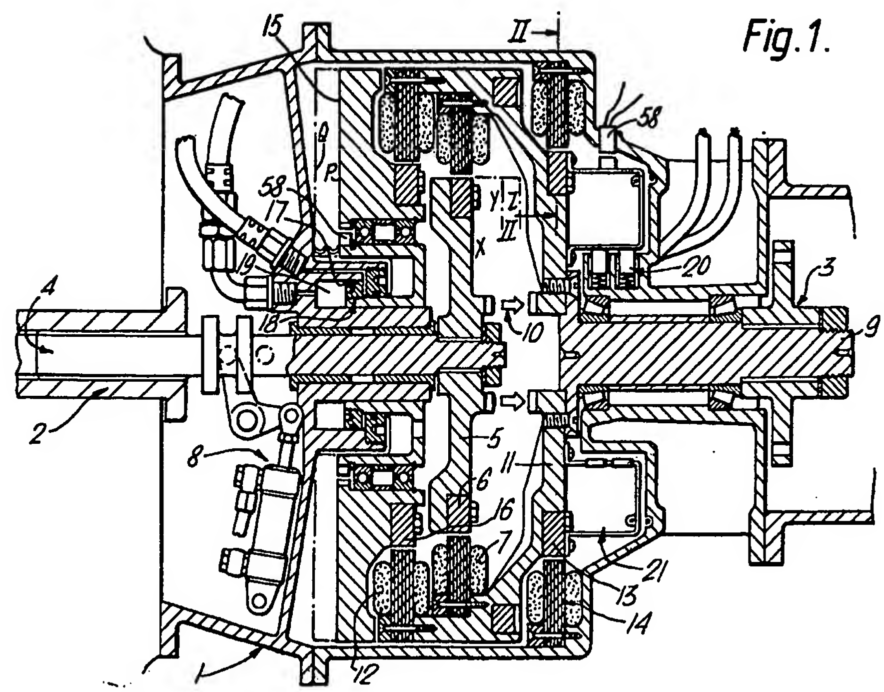
(54) Hybrid machines, and vehicles powered thereby

(57) A transmission system, for a hybrid machine comprising a heat engine as prime mover and a dynamoelectric device, includes a flywheel (15) for storing kinetic energy and electrodynamic couplings (12, 16; 6, 7; 13, 14) selectively operable for transmitting torque from the prime mover *via* shaft 4 to the flywheel and/or to the output *via* 9, and/or for transmitting torque between the flywheel and the output. Actuator 8 shifts rotor 5 selectively into positions X, Y or Z; actuator 17 shifts flywheel 15 into positions P or Q. Batteries are connected *via* slip rings 20. An external control system is disclosed using Hall effect devices 58 and a microprocessor to obtain optimum performance. Various operational modes are described.



The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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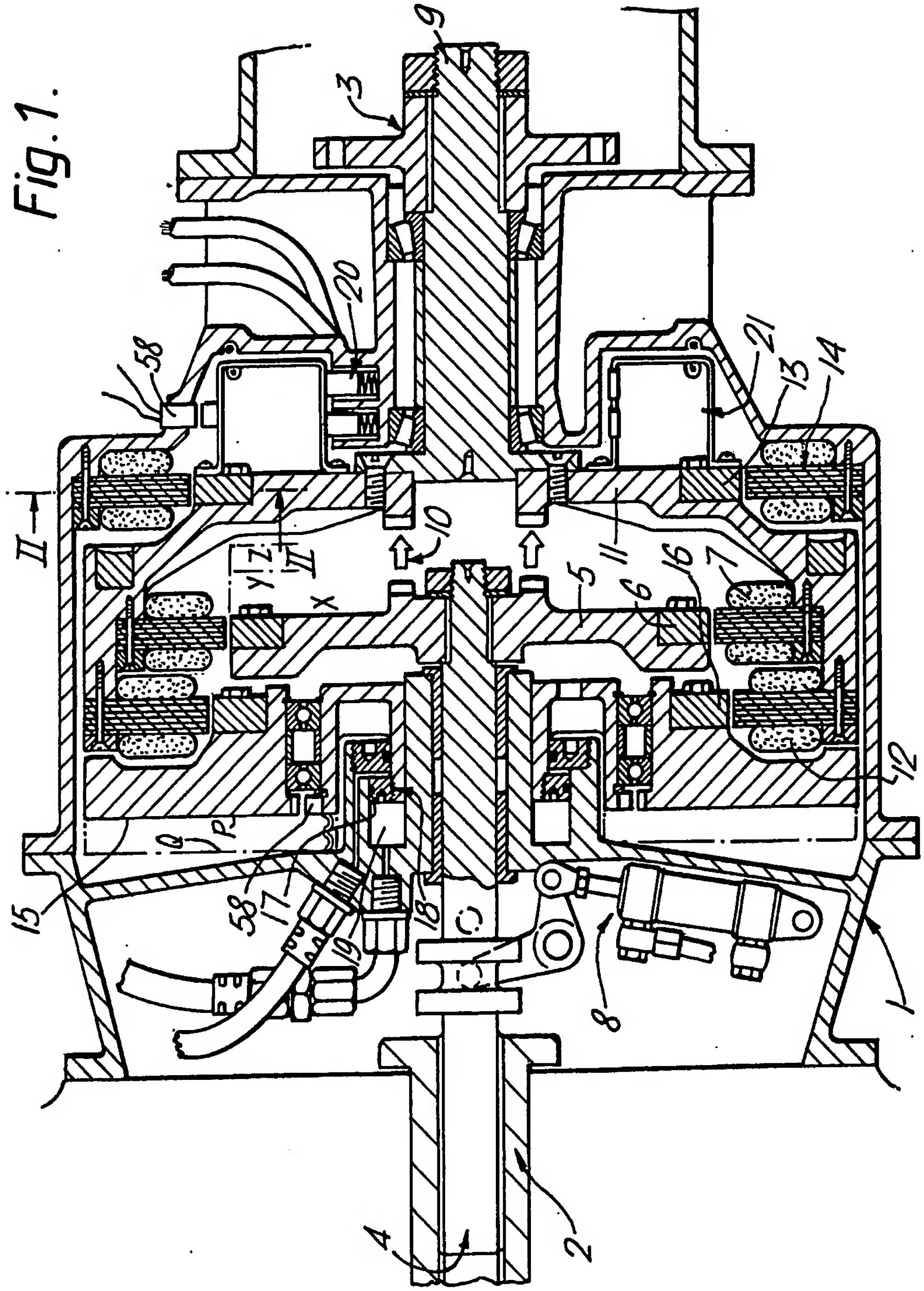
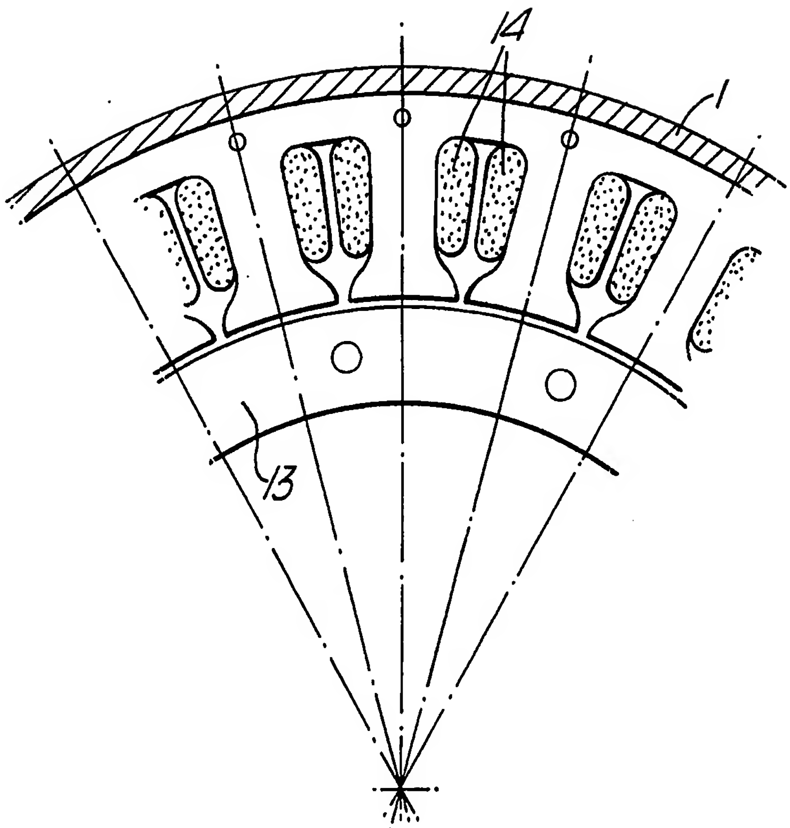


Fig.1.

Fig. 2.



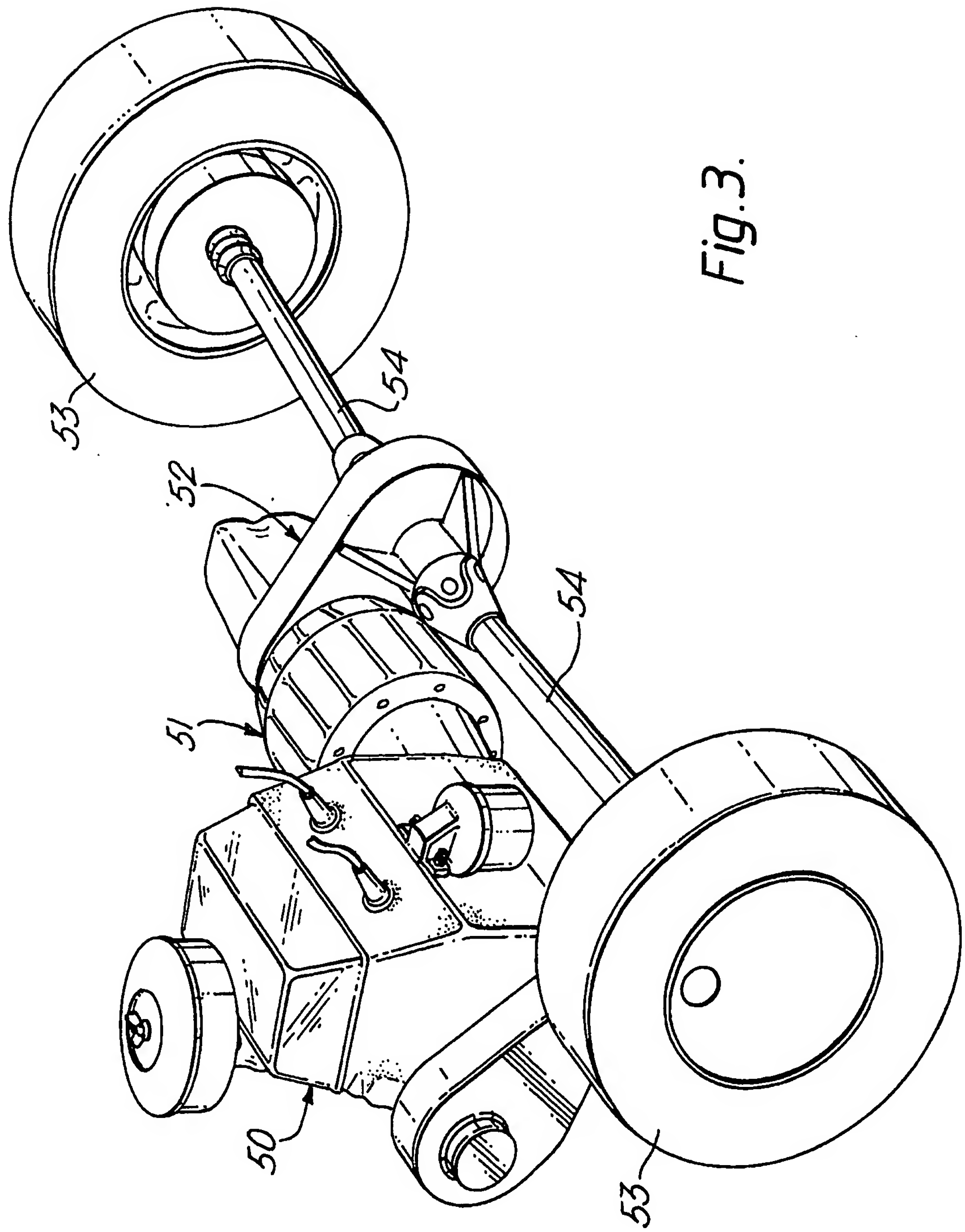


Fig.3.

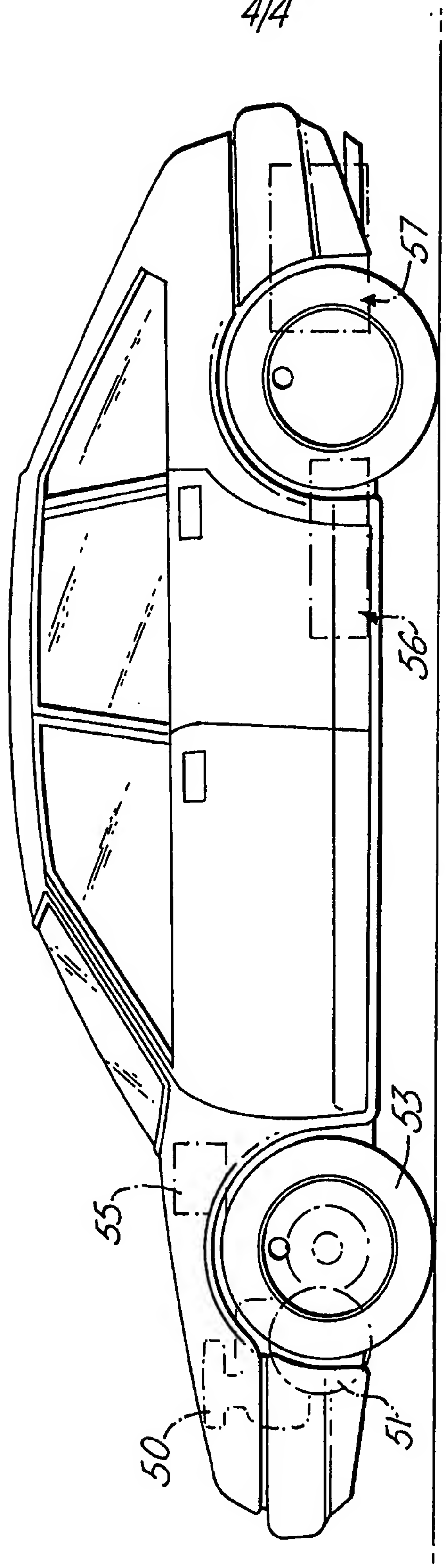


Fig. 4.

SPECIFICATION

Hybrid machines, and vehicles powered thereby

This invention relates to hybrid machines, that is to say, machines adapted to utilise energy drawn selectively from two or more sources, the invention being especially applicable to vehicles, such as road vehicles, incorporating hybrid machines as a motive power source.

Many proposals have been made for vehicles to utilise electric motors and internal combustion (IC) engines in various combinations as motive power sources, the diesel/electric locomotive being one example of such a vehicle and that in some forms is capable of operation from an internal source of electricity when available. Another example is the proposed battery electric vehicle equipped with a motor-generator for battery-charging.

These are examples of the so-called "series" hybrid IC/electric machine and are characterised by being heavy, bulky and costly and of rather low efficiency by reason of losses in converting the energy of the fuel for the IC engine to machine output power through the generation and utilisation of electrical energy, and consequently are not suited for adaptation to vehicles such as private motor cars.

With the objective of avoiding these disadvantages of the series hybrid, the "parallel" hybrid system has been proposed, in which an IC engine provides direct drive for the machine output that is also connected to an electric motor-generator drawing energy from a battery to boost the output power when required, and returning energy to the battery when the output power demand is low or negative (regenerative braking). This system tends to be smaller, lighter and cheaper than the series hybrid, but suffers from the disadvantage of the combustion engine being directly coupled to the machine output and therefore having to operate over the full output speed range: for vehicle applicaions, this implies a substantial loss of potential IC engine efficiency and the added complication of variable ratio transmission from the machine output to the vehicle wheels.

By its nature, the motor-generator of the typical "series" hybrid IC/electric machine stores considerable kinetic energy that can be released to boost output electrical power to meet acceleraion demands when required, by allowing the motor-generator set to slow under such conditions, without seriously impairing the operating efficiency of the IC engine. This effect can be enhanced by the inclusion of a suitable flywheel in the motor-generator set. The direct coupling of the IC engine to the machine output in the parallel hybrid generally rules out this utilisation of stored kinetic energy.

One object of the invention is to provide a transmission system for a hybrid heat engine/electric machine such as to enable the latter to realise advantages of both the series and the parallel systems as discussed, while avoiding their respective discussed disadvantages. A further object is to provide a hybrid heat engine/electric machine especially suitable to provide motive power for a road vehicle such as a private car.

Accordingly one aspect of the invention provides a transmission system for a hybrid machine comprising a heat engine as prime mover and a dynamoelectric device, the transmission system including a flywheel for storing kinetic energy, an input element for connection to the heat engine and an output element for connection to the dynamoelectric device, and electrodynamic coupling means operable to transmit torque selectively from the input element to said flywheel and/or to said output element, and/or to transmit torque between the flywheel and the output element.

The output element of the transmission may be arranged for connection to a self-contained compatible dynamoelectric device as by a suitable mechanical coupling. Preferably, however, the dynamoelectric device is integrated with the transmission system, the output element constituting the rotor of the dynamoelectric device.

Therefore another aspect of the invention provides a transmission system comprising an input element adapted to be connected to a heat engine as prime mover, a dynamoelectric device coupled to an output element, a flywheel for storing kinetic energy, and electrodynamic coupling means operable to transmit torque selectively from the input element to the flywheel and/or to the output element and/or to transmit torque between the flywheel and the output element.

In the case of hybrid machines intended for use in situations in which a primary source of electrical energy is available, e.g. a mains supply or a fuel cell, the dynamoelectric device may be arranged for connection to such a source, to draw energy therefrom when required by the duty cycle of the machine. In the usual application, however, for instance as the motive power source for a road vehicle, the dynamoelectric device will be adapted for connection to an electrical storage means such as a battery of secondary cells, arranged to be charged by generation of electrical energy by the heat engine and/or by regenerative braking during appropriate parts of the machine duty cycle.

The input element preferably comprises means for releasably mechanically engaging the output element to provide for direct torque transmission from the input element to the output element and to avoid energy transformation losses during parts of the duty cycle when the output element load and speed requirements are appropriate for direct coupling to the heat engine without detriment to the efficient operation thereof. The electrodynamic coupling means may be controlled by a microprocessor or other programmed or programmable controller.

Depending upon the characteristics of the heat engine, the output speed requirements and the torque and power-transmitting capabilities of the electrodynamic coupling means, the heat engine may be coupled directly to the input element of the transmission or it may be coupled to the latter through a speed-changing device such as a gearbox. Likewise the output element may be coupled directly to a final driven element or it may be coupled to the latter through a speed-changing device.

Thus to enable the torque load on the transmis-

sion to be minimised and thereby facilitate a compact construction of the transmission for a given power transmitting capacity, the heat engine may be coupled to the input element through a speed-increasing device, and the output element coupled to the final driven element through a speed-reducing device, the transmission elements thus operating at a higher speed than the engine and the final driven element.

The speed ratios of the respective speed-changing devices might be the same or different depending upon requirements. However, by arranging the speed-changing devices with corresponding ratios, direct drive between the engine and the final driven element could be obtained by a simple mechanical coupling, such as a clutch, to minimise losses in the speed-changing devices, when such direct drive is desired in a duty cycle. Such direct drive, by-passing the transmission and the speed-changing devices, could supplement or replace the described direct drive between the input and output elements of the transmission for similar purposes.

An embodiment of the invention is illustrated by way of example in the accompanying drawings, which show a transmission system for a hybrid machine adapted to provide the motive power for a road vehicle, and in which:

Figure 1 is a schemaic axial sectional view of a transmission system embodying the invention;

Figure 2 is a scrap section on line II-II of Figure 1;

Figure 3 illustrates a possible layout of a hybrid machine incorporating the transmission of Figures 1 and 2 as a power unit for front wheel drive of a motor road vehicle; and

Figure 4 illustrates a passenger car and a possible distribution of the power unit of Figure 3 and related components.

Figures 1 and 2 of the drawings illustrate a transmission system comprising a housing 1 with coaxial input and output elements 2, 3 respectively, the input element 2 being intended to be coupled mechanically to an internal combustion (IC) engine, whereas the output element 3 is intended for connection, perhaps through a change-speed or variable ratio drive mechanism, to driving road wheels of a motor road vehicle. Figure 3 illustrates one possible layout, for front wheel drive in which an internal combustion engine 50 (e.g. a small diesel, or stratified charge engine) is disposed transversely of the vehicle, and the output of the transmission, shown generally a 51, is connected to a final drive and change-speed gearbox 52 driving road wheels 53 through suitable driveshafts 54. Figure 4 shows how this power unit might conveniently be incorporated in a passenger car in association with a microprocessor control system 55, a tank 56 for fuel for the IC engine, and a battery 57 of electrical storage cells.

The input element 2 includes an input shaft 4 and an input rotor 5 carrying one element, in this case a radially polarised ring magnet 6 consisting of, say, 20 to 50 radially polarised segments, of an electrodynamic coupling the other element of which is a ring of coils 7. An actuator 8 is arranged to move the input shaft 4 axially so that the rotor can be shifted to occupy, selectively, three positions, X, Y and Z, in one of which, position X, shown in full lines in the drawing, the ring magnet 6 registers with the coils 7.

The output element 3 comprises an output shaft 9 that is coaxial with the input shaft 4 and is arranged for direct mechanical coupling to the latter by means of a dog clutch 10 when the input shaft 4 and the rotor 6 are shifted to the position Z of the rotor. The output element also includes an output rotor 11 that carries the coils 7, another ring of coils 12 that constitute one element of a second electrodynamic coupling, and also a radially polarised ring magnet 13 that forms the rotor of a dynamoelectric device the stator of which consists of a ring of coils 14 carried by the housing 1.

A flywheel 15 is mounted concentrically of the input shaft 2 for free rotation relative thereto and carries a radially polarised ring magnet 16 that cooperates with the coils 12 of the second electrodynamic coupling. The flywheel 15 is arranged for axial movement on the input shaft 2 by means of a hydraulic actuator 17 comprising an annular piston 18 operating in an annular chamber 19. In the flywheel position shown, position P, the ring magnet 16 registers with the coils 12, whereas in the flywheel position Q the magnet 16 is removed from the influence of the coils 12.

A set of slip rings 20 on the output shaft 4 provides for connection of a battery of electrical storage cells of the coils 7 and 14 as required to achieve selective operation of the two electrodynamic coupling, the association of the coils 7 and 14 with the slip rings being controlled by suitable control mechanism (not shown) housed in an annulus 21 on the output rotor 11 and in turn actuated by signals from an external control system, conveyed to the controlled mechanism optically, inductively or by super-imposition on the slip ring connections. The external control system preferably includes a microprocessor arranged to receive output demand signals and also speed signals from the input element, from the flywheel 15 and from the output element 3, e.g. by Hall effect devices 58, and programmed to activate the electrodynamic couplings by energising coils 7 and 14 the actuators 8 and 17 and operating controls of the IC engine, to achieve optimum operation of the IC engine and utilisation of the kinetic energy of the flywheel 15 and of the stored electrical energy throughout the duty cycle of the machine.

Thus, in a duty cycle, the described hybrid machine may utilise energy from three sources or stores; the internal combustion engine, the electrical storage cell battery and the flywheel 15. The load demand on the output element may be met continuously or intermittently by power drawn from either the IC engine or the battery, or from both, and additional power may be drawn transiently from the flywheel.

In a typical duty cycle, the IC engine operates continuously at its optimum efficienty and provides the basic energy source to meet the output demand: when the optimum efficiency power level of the IC engine is above the output demand level the excess available power of the IC engine is used to store electrical energy in the battery and kinetic energy in

the flywheel so that, when the power demand level exceeds the optimum power level of the IC engine, these other sources can supply the deficit.

Following the above operating principle, coils 7, 12 and 14 can be selectively switched to provide different modes of operation. Each coil has a connection mode in which it receives power from the battery to transmit torque to or from its corresponding ring magnet, i.e. the input rotor 5, the flywheel 15 and the output rotor 11 can be driven by energising coils 7, 12 and 14 respectively. The electrodynamic coupling coils 7 and 12 are capable of being switched repeatedly between short and open circuit, short-circuiting coils 7 inducing the output rotor 11 to follow the rotation of the ring magnet 6 on the input rotor 5 and short-circuiting the coils 12 inducing the output rotor 11 to follow the rotation of the ring magnet 16 on the flywheel 15. The ratio of short to open circuit periods in a duty cycle for these coils determines the torque transferred to the output shaft 9. The coils 7 and 14 are also connectible for generation of electrical energy for battery charging.

A typical duty cycle in the operation of the illustrated machine as the motive power source of a vehicle might comprise the following phases:

Start-up

Actuator 8 is operated to position the input rotor 5 in position X and electrical power from the battery is supplied to coils 7 to rotate the input rotor 5 and input shaft 4, for starting the IC engine.

Warm-up(no load)

The IC engine is put in no-load conditions until it warms up, by the actuator 8 moving the input rotor 5 into position Y. If drive to the wheels is required during this phase, coils 14 are energised from the battery and the vehicle is run in an all-electric mode.

Normal-running

The input rotor 5 is shifted to position X and coils 7 are intermittently short-circuited so that output rotor 11 is driven by the IC engine via the electrodynamic coupling consisting of coils 7 and magnet 6. The IC engine is set to run at optimum efficiency power output.

During such normal running, say with the vehicle cruising at 50 mph, the optimum efficiency output power level of the IC engine will exceed that required to drive the vehicle, and coils 14 can be switched to generative action and/or coils 12 can be energised (either by generated or by stored electrical energy) to spin up the flywheel, any increased torque required by the output rotor to support these modes being supplied by increasing the ratio of short to open circuit periods in coils 7. When the flywheel is running at full speed or energy is not available to increase its speed, actuator 17 retracts the flywheel to position Q and coils 12 are switched to open circuit so that there is minimum loss of energy from the flywheel.

When the flywheel is running at full speed and the battery is fully charged, the vehicle may be run on a time sharing basis between the all-electric mode, drawing power from the battery with the combustion engine shut down, and electrodynamically coupled drive from the combustion engine with simultaneous recharging of the battery.

Acceleration

If rapid acceleration is required, the actuator 17 is operated to move the flywheel to position P and coils 12 are intermittently short-circuited so that the kinetic energy in the flywheel is electrodynamically transmitted to the output rotor 11. The power supplied by the flywheel to the output rotor is adjusted by control of the ratio of short to open circuit periods in coils 12, and/or by movement of the flywheel to positions intermediate P and Q, the flywheel being returned to position Q when its energy contribution has been completed.

Optimum cruising speed

At a particular cruising speed the required power output corresponds to the optimum efficiency power output level of the IC engine. The speed ratio between the vehicle drive wheels and the output shaft 4 is preferably so selected that at this speed, and with the IC engine at its optimum efficiency power output levels, the speeds of the input and output shafts coincide.

Under these conditions, therefore, the input shaft may be shifted to position 2 so that the dog clutch 10 is engaged and torque is transmitted directly to the output shaft 9 without incurring energy transformation and other losses in the electrodynamic coupling.

Depending on the type of IC engine associated with the input shaft, and its speed/power/efficiency characteristics, such direct drive through the dog clutch 10 may be employed over a range of vehicle operating speeds and if appropriate energy may be transferred between the input rotor/output rotor assembly and the flywheel and/or the batery to enable the IC engine to operate at an appropriate output power level for optimum efficiency at any speed within the direct drive speed range.

The vehicle may be accelerated to, and maintained at, speeds above that corresponding to the maximum available IC engine power output by supplementing the IC engine power with energy drawn from the flywheel (for acceleration as described) and from the storage battery.

Braking

Regenerative braking techniques may be applied by switching coils 14 to generate and/or by moving the flywheel to position P and switching coils 12 to spin-up the flywheel, and/or by switching coils 7 to generate. The braking effect caused by these techniques may be supplemented, e.g. for final stopping, by normal wheel brakes.

During a normal duty cycle the battery and flywheel should not be permitted to be depleted of energy and suitable override controls may be provided to prevent this circumstance arising, e.g. by limiting output power to less than the available IC engine power while the stored energies in the flywheel or battery are below prescribed levels. Such override controls may be incorporated in a microprocessor or programmable controller used to control

the switching sequence of the coils 7, 12 and 14 and actuators 8 and 17.

In a typical embodiment of the invention the input shaft 2 may be arranged for rotation at any speed suited to the IC engine with which the transmission is to be associated and could for instance be arranged for rotation at 2500 rpm. The flywheel 15 would preferably have a maximum speed in the range 10000 - 20000 rpm and be sized to store, at maximum speed, say 80KJ of kinetic energy releasable to the output rotor, when required, within a period of, say, 8 seconds by transfer through the appropriate electrodynamic couplings.

As previously noted the required torque capacity of the transmission for a given power transmitting capability may be reduced by arranging for the transmission input and output elements to operate at a higher speed than the IC engine and the final driven element. In the layout of Figure 3, the final drive may have any suitable speed-reduction ratio as above described for optimium cruising conditions, and if required this ratio may be increased in correspondence with the speed-increasing ratio of a suitable gearbox connecting the IC engine to the input shaft 4, for the purpose of operating the transmission at higher-than-engine speeds.

However, a preferred arrangement would involve a step-up gearbox between the IC engine and the shaft 4, and a step-down gearbox of primary reduction stage in the connection between the output shaft 9 and the final drive and change-speed gearbox 52, with means such as a clutch for coupling the IC engine directly to the fina drive to unload the transmission and minimise losses in this and the gearboxes when the duty admits of economic direct drive. The step-up and step-down ratios of the engine-to-transmission and transmission-to-final drive gearboxes or equivalent might, for instance, be 1:10 and 10:1 respectively, to reduce the torque capacity requirement of the transmission by a factor of ten as compared with direct coupling of the IC engine to the transmission.

The described electrodynamic couplings are merely illustrative of coupling constructions that may be utilised. For instance the ring magnets may be substituted by other permanent or electromagnetic magnet structures, and different coil configurations may be used. The individual coils of each coupling are preferably arranged for variable interconnection in several different polyphase configurations by the control system in order to provide for appropriate control of the torque transmission characteristics of the coupling under varying operating conditions experienced in a duty cycle.

CLAIMS

1. For a hybrid machine comprising a heat engine as prime mover and a dynamoelectric device, a transmission system includig a flywheel for storing kinetic energy, an input element for connection to the heat engine and an output element for connection to the dynamoelectric device, and electrodynamic coupling means operable to transmit torque selectively from the input element to said flywheel and/or to said output element, and/or to transmit torque between the flywheel and the output element.

2. A transmission system comprising an input element adapted to be connected to a heat engine as prime mover, a dynamoelectric device coupled to an output element, a flywheel for storing kinetic energy, and electrodynamic coupling means operable to transmit torque selectively from the input element to the flywheel and/or to the output element, and/or to transmit torque between the flywheel and the output element.

3. A transmission system according to claim 1 or 2, including speed-increasing means for connecting said input element to the heat engine.

4. A transmission system according to claim 3, including speed-reducing means for connecting said output element to a final driven element, such speed-reducing means having the same ratio as the said speed-increasing means, and means for selectively establishing direct mechanical coupling of the heat engine to the final driven element.

5. A transmission system according to any one claims 1 to 4, in which the input element comprises means for releasably mechanically engaging the output element.

6. A transmission system according to claim 5, in which said means comprises a dog clutch.

7. A transmission system according to any preceding claim, in which the output element comprises a shaft coupled to a rotor carrying first elements of electrodynamic coupling means associated with individual second coupling elements on the flywheel and the input element, respectively.

8. A transmission system according to claim 7, in which the first elements of the electrodynamic coupling means comprises coils on the rotor.

9. A transmission system according to claim 7 or 8, in which the second coupling element comprise permanent magnets.

10. A transmission system according to any preceding claim, in which the output element comprises the rotating element of the dynamoelectric device.

11. A transmission system according to claim 10, in which said rotating element of the dynamoelectric device comprises a permanent magnet system.

12. A transmission system according to any preceding claim, in which the dynamoelectric device is adapted for regenerative connection to electrical energy storage means.

13. A transmission system substantially as hereinbefore described with reference to and as shown in Figures 1 and 2 of the accompanying drawings.

14. A hybrid machine comprising a transmission system according to any preceding claim.

15. A hybrid machine according to claim 14, in which the operation of the electrodynamic coupling means is controlled by a microprocessor.

16. A vehicle comprising a hybrid machine according to claim 14 or claim 15, as its motive power source.

17. Every novel feature and every novel combination of features disclosed herein.

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